(12) UK Patent Application (19) GB (11) 2 093 589 A

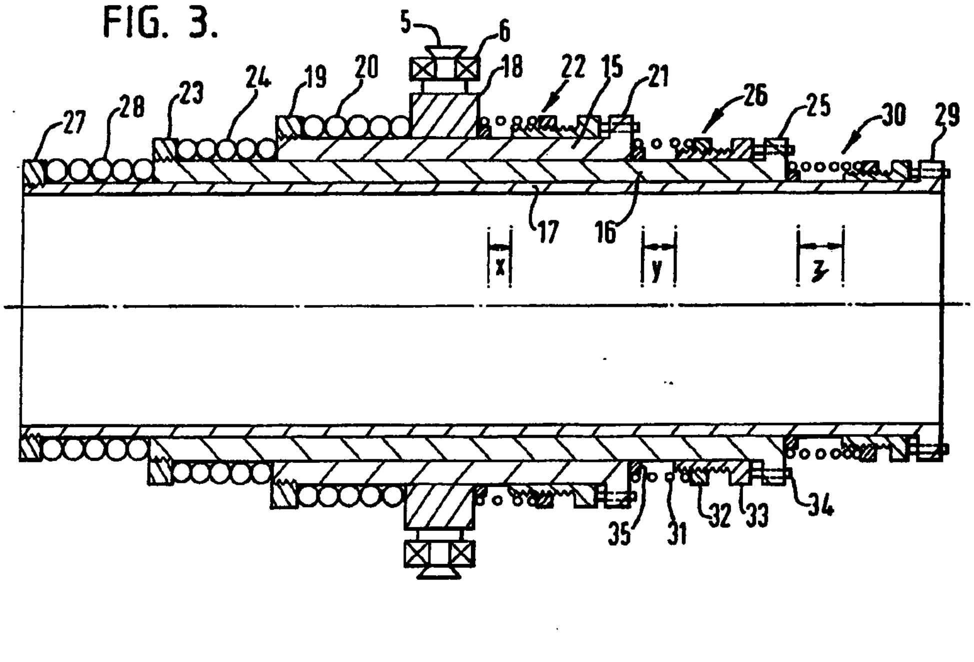
(21) Application No 8204240
(22) Date of filing 12 Feb 1982
(30) Priority data
(31) 8105542
(32) 21 Feb 1981
(33) United Kingdom (GB)
(43) Application published 2 Sep 1982
(51) INT CL[3] G01K 11/00
(52) Domestic classification G1D 10X2
(56) Documents cited
GB 1554738
GB 1169229
(58) Field of search G1D

(71) Applicants
Pilkington PE Limited,
Prescot Road,
St. Helens,
Merseyside WA10 3TT.
(72) Inventors
Geoffrey Martin Garness
(74) Agents
Withers & Rogers,
4 Dyer's Buildings,
Holborn,
London EC1N 2JT.

(54) Improvements in or relating to temperature responsive actuators particularly for optical systems

(57) A temperature responsive actuator has coils (20, 24, 28) of "Shape Memory Effect" material which expand and contract over different respective temperature ranges and are arranged in series to provide an output over a relatively broad operating temperature range incorporating the different respective ranges. Respective biassing mechanisms (22, 26, 30) apply a biassing load to the SME elements to produce a substantially linear actuator output. The actuator is particularly useful for an infra-red optical system to displace an infra-red lens element and thereby compensate for temperature change to which the element is sensitive.

FIG. 3.



The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

GB 2 093 589 A

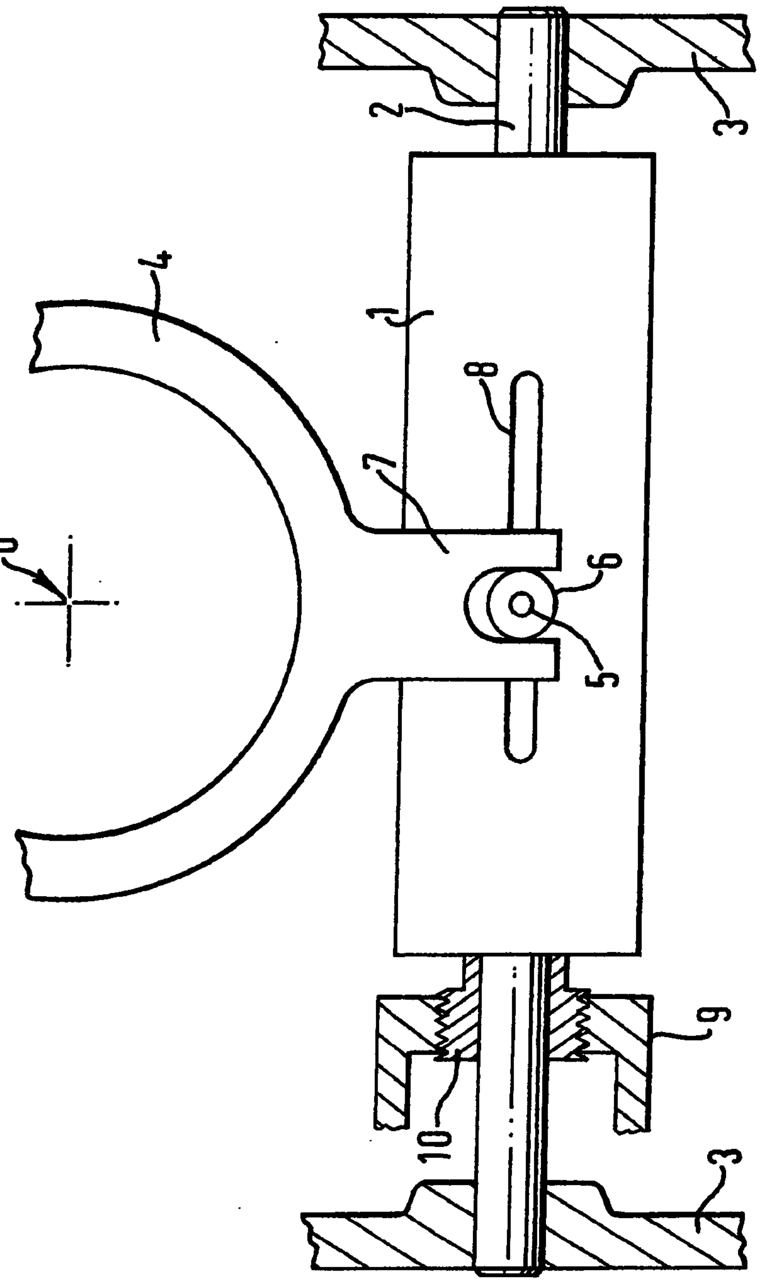
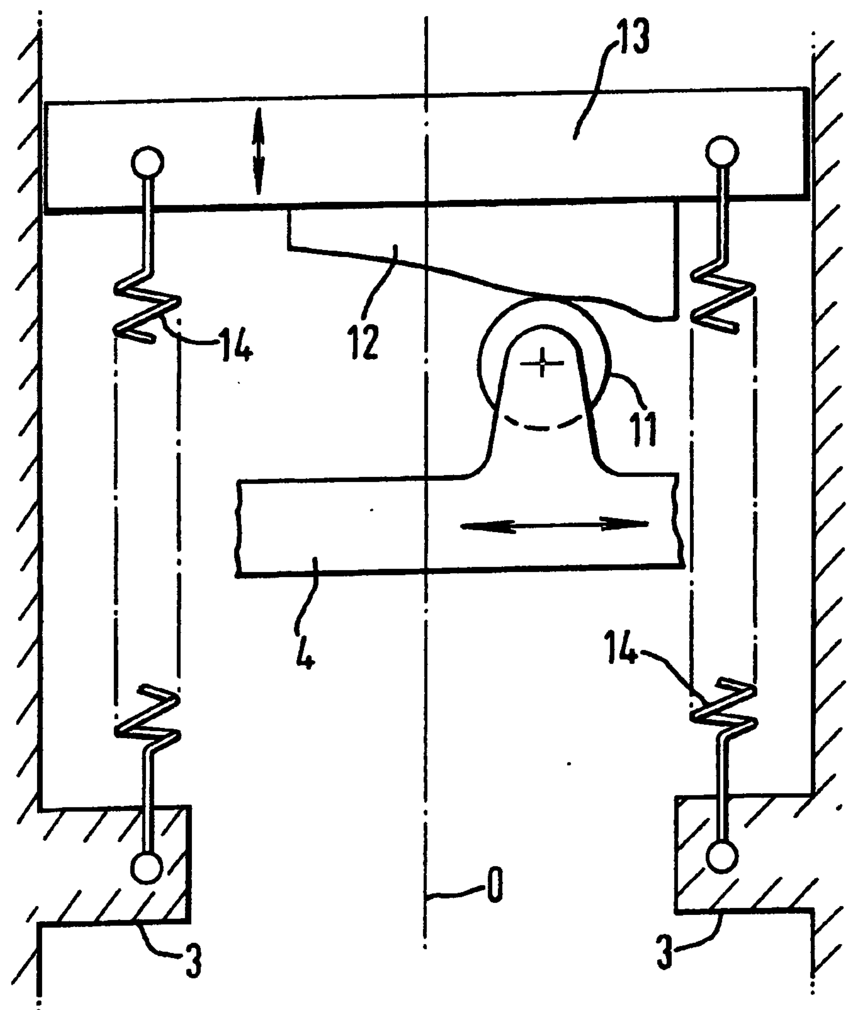


FIG. 1.

FIG. 2.



accordance with the invention could be used for purposes where temperature responsive actuation is required other than in optical systems, especially where linearity of output is essential.

The actuator may be operatively connected with an angularly movable or rotatable member, such as a ring, for example disposed round an optical axis. Such member may by angular movement cause linear movement of another member, for example a sliding lens carriage which is to be displaced along the optical axis, by means of a cam and cam follower arrangement. For example, a plurality of equi-spaced basically ramp-like cams may be mounted on one of the members for engagement by a corresponding plurality of equi-spaced cam follower rollers mounted on the other member. The cam surfaces may be profiled to effect a required movement, e.g. to compensate for small residual non-linearity of the actuator output.

"Shape Memory Effect" material is a known material having peculiar temperature responsive characteristics and may in particular consist of an alloy of brass. It is obtainable from Delta Memory Metal Company Limited of Ipswich.

Apparatus in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Figure 1 is a schematic representation of an actuator and connected mechanism drawn in a plane orthogonal to an optical axis of an optical system incorporating the actuator,

Figure 2 is a schematic representation showing further parts of the mechanism and drawn in a plane parallel to the optical axis,

Figure 3 is a schematic representation of the actuator in longitudinal cross-section,

Figure 4 is a schematic representation of part of a biassing mechanism in longitudinal cross-section,

Figure 5 is a schematic representation of part of the biassing mechanism of Figure 4 in transverse cross-section,

Figure 6 is a schematic representation of part of an alternative form of biassing mechanism in longitudinal cross-section, and

Figure 7 is a graphical representation of the load/deflection/temperature characteristics of a typical "Shape Memory Effect" material coil.

Figure 1 schematically shows a temperature responsive actuator 1 (more fully described later) carried on a shaft 2 whose ends are fixed to a housing 3 of the optical system. The actuator 1 is operatively connected to a rotating ring 4 which can move angularly about an optical axis O. The actuator has projecting stub shafts 5, each carrying a roller 6, disposed at two diametrically opposed positions (only one shaft 5 and roller 6 being visible in Figure 1). Arms 7 of the ring 4 have recessed or slotted ends in which the rollers 6 are located. In action the actuator causes linear movement of the stub shafts 5 so that they slide along slots 8 whereby the ring 4 is caused to move angularly through engagement of its arms 7 on the rollers 6.

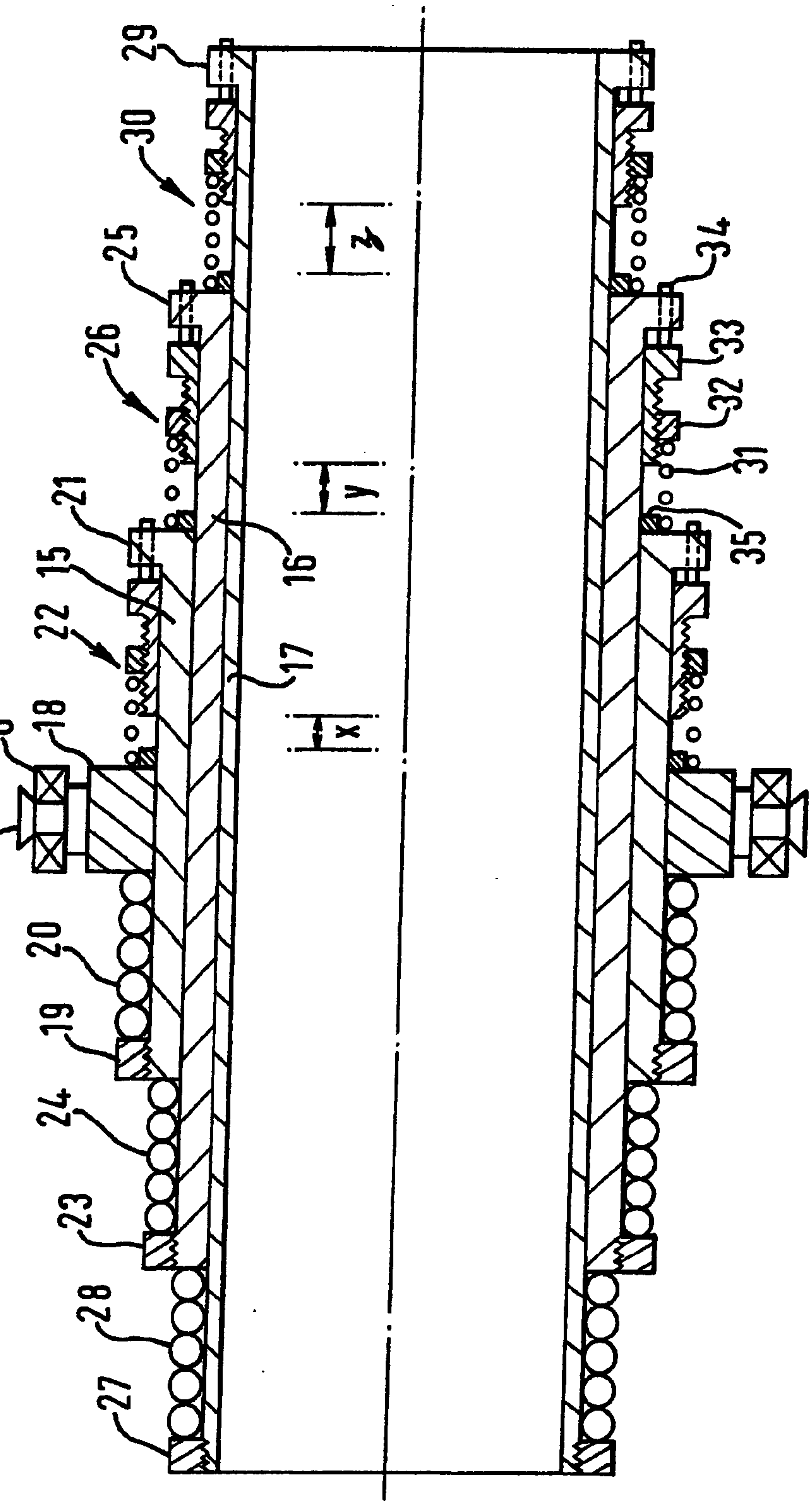
At one end of the actuator 1 there is a calibration device comprising a nut 9 in screw threaded engagement with a member 10 mounted on the shaft 2 and connected to the actuator. The nut 9 can be rotated, either manually by direct access if desired remotely by a direct drive torque motor or a motor and gearhead, to shift the reference point of the actuator as may be required for occasional calibration.

Referring now also to Figure 2, the ring 4 carries on its front face three equi-spaced rollers 11 (only one of which is shown in Figure 2). Each of these rollers engages against a ramp cam 12 mounted on a sliding lens carriage 13, there being three equi-spaced ramp cams 12 on the lens carriage corresponding to the three rollers 11 on the ring 4. Tension springs 14 connected between the lens carriage 13 and the housing 3 maintain the ramp cams 12 in engagement with the rollers 11. Thus, as the ring 4 moves angularly about the optical axis O the lens carriage 13 is caused to move along the optical axis O. Specifically, as viewed in Figure 2, when the ring 4 rotates so as to move the roller 11 to the right the lens carriage 13 will move upwardly (forwardly), and when the ring 4 rotates so as to move the roller 11 to the left the lens carriage 13 will move downwardly (rearwardly). A lens element (not shown) mounted in the lens carriage 13 thus has its position along the optical axis O adjusted responsively to angular movement of the ring 4 which is, as described above, effectively tangentially driven by the actuator 1.

If the temperature responsive actuator output is linear, i.e. bears a straight line relationship to temperature over the range of operation, then the operative surface of the ramp cams 12 can be planar to produce corresponding linear motion of the lens carriage 13. In practice some small departure from linearity of actuator output may be tolerable and planar cam surfaces may still be used where the lens element position tolerance so allows. However, if desired or necessary, the operative surface of the ramp cams 12 may be profiled (and is shown profiled in Figure 2) to compensate for or counteract non-linearity of actuator output.

Figure 3 schematically shows the temperature responsive actuator 1 in longitudinal cross-section. It comprises three concentric cylindrical sleeves 15, 16 and 17 which are relatively slidable, i.e. the outer sleeve 15 can slide along the middle sleeve 16 and the middle sleeve 16 can slide along the inner sleeve 17. Round the outer sleeve 15 is an annular sliding member 18 which carries the stub shafts 5 and rollers 6 projecting at diagonally opposed positions as previously mentioned with reference to Figure 1. Between the member 18 and an end rim 19 of the outer sleeve 15 there is a first coil 20 of "Shape Memory Effect" material (referred to hereafter as SME) one end of which abuts the member 18 and the other end abuts the rim 19. Between the member 18 and the other end 21 of the sleeve 15 is a biassing mechanism 22 more fully described later. Expanson of the SME coil 20, i.e. increase in its effective length, resulting from a rise in temperature, causes the member 18 to move along the sleeve 15 to the right as viewed in Figure 3 against the biassing action of the mechanism 22. The coil 20 is shown in Figure 3 in its fully contracted state, but when in an expanded state contraction of the coil resulting from a drop in

FIG. 3.



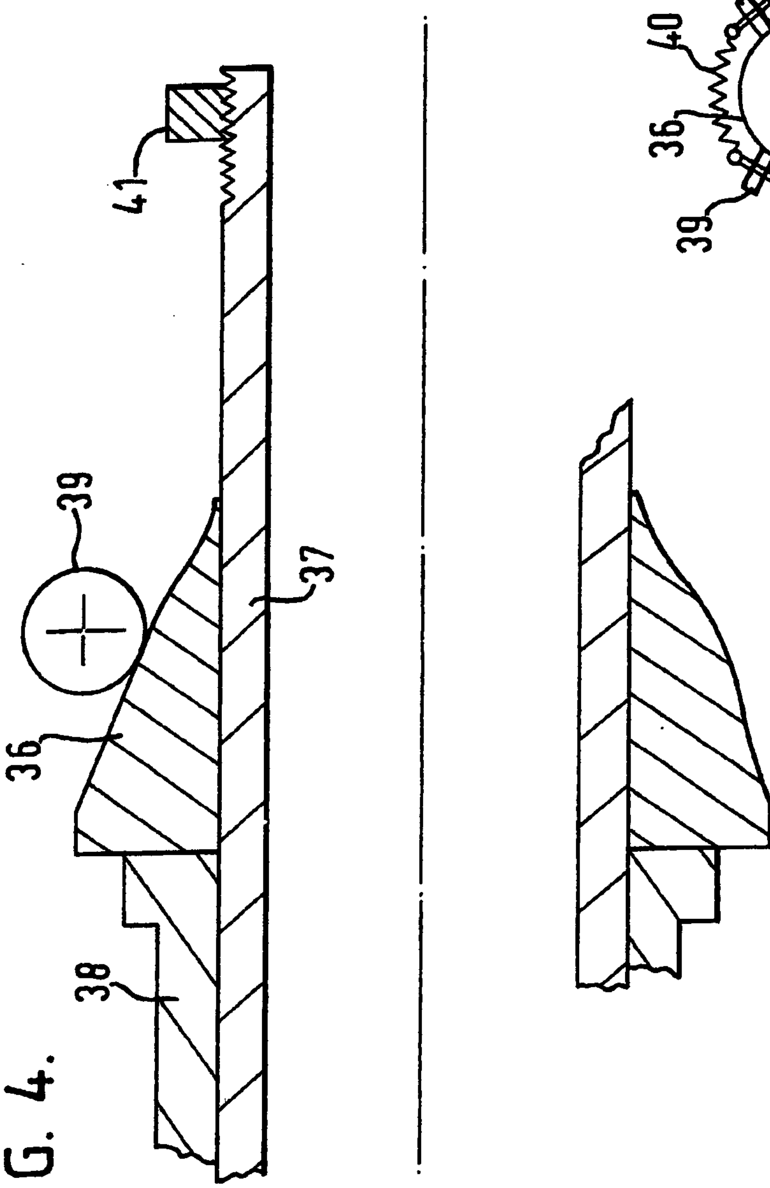


FIG. 4.

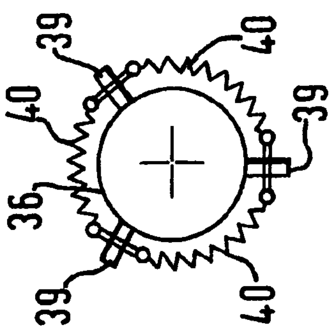


FIG. 5.

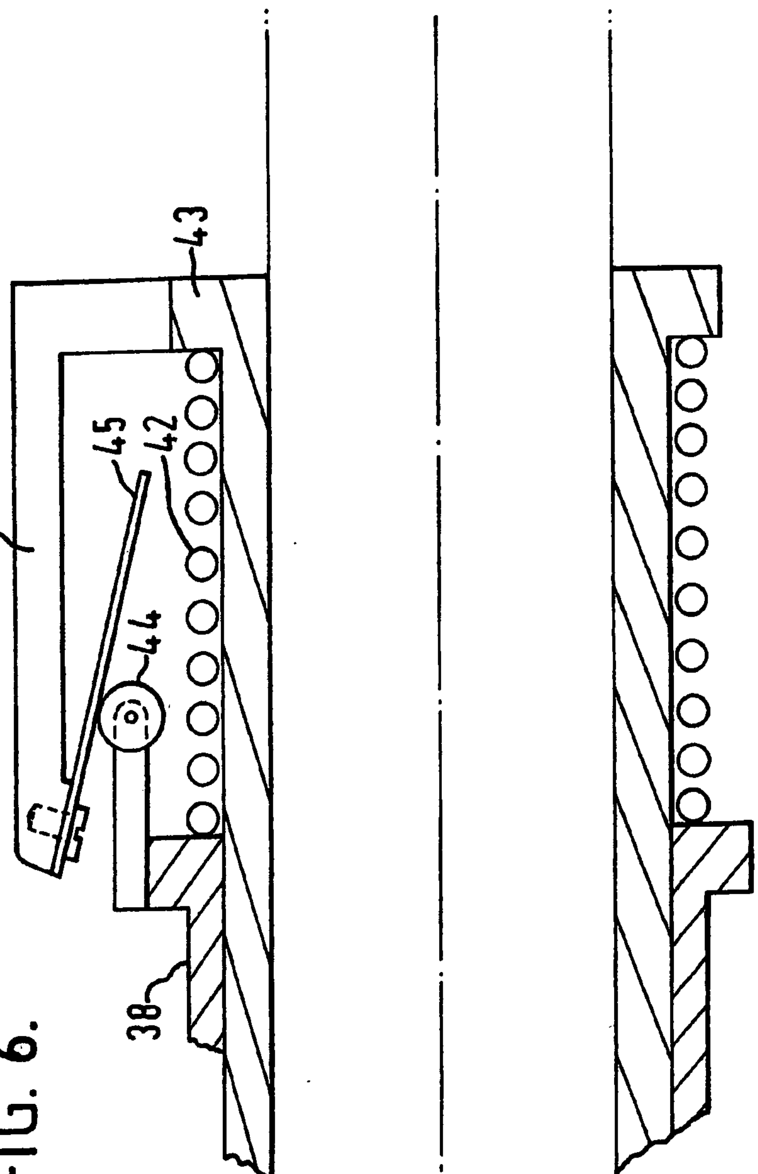
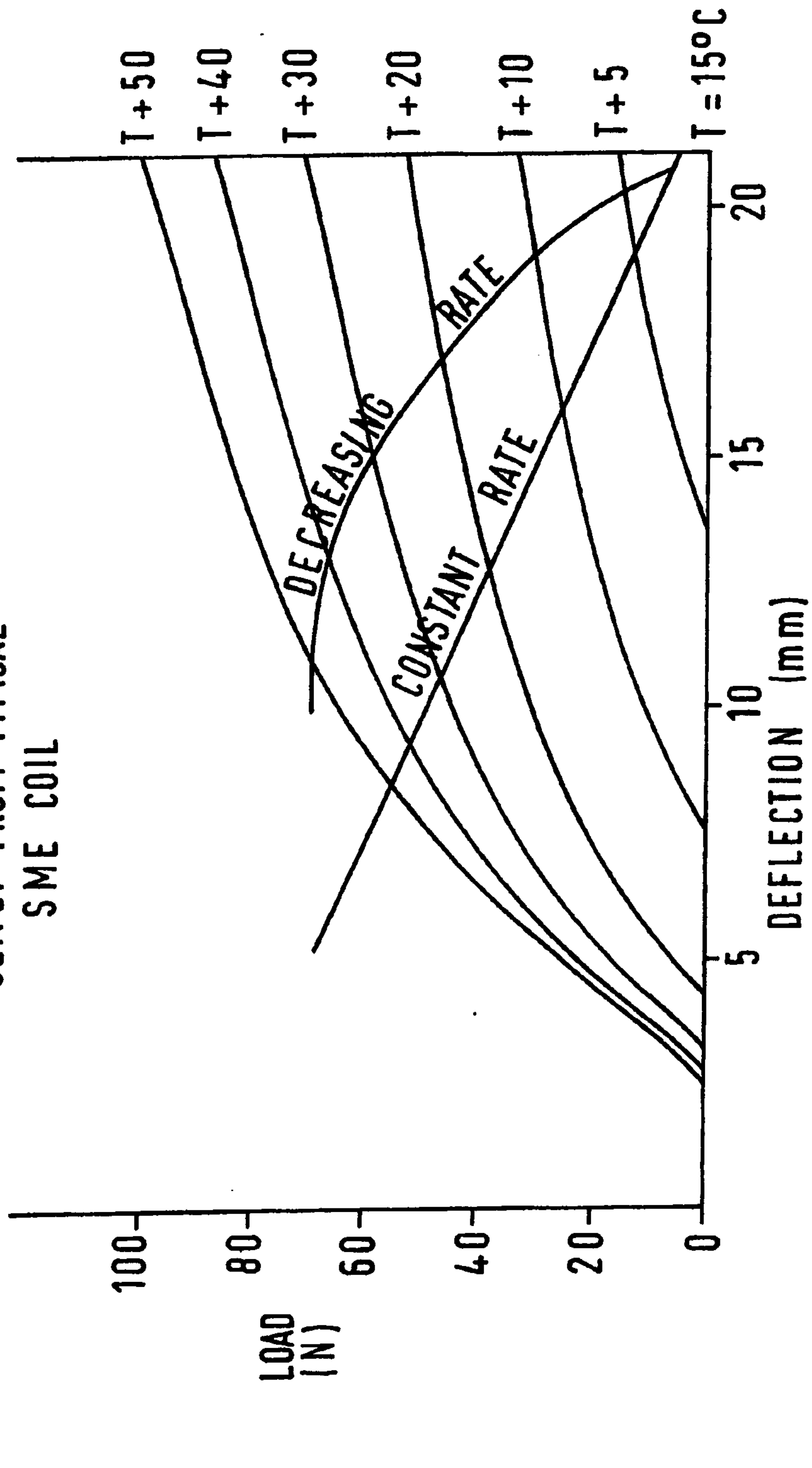


FIG. 6.

FIG. 7.

OUTPUT FROM TYPICAL SME COIL



SPECIFICATION

Improvements in or relating to temperature responsive actuators particularly for optical systems

This invention concerns improvements in or relating to temperature responsive actuators and relates further to optical systems, and particularly infra-red optical systems, employing such an actuator.

Infra-red transmitting materials suitable for use in infra-red optical systems, such as infra-red lenses, are generally temperature sensitive. Thus, temperature changes can significantly alter the relevant optical properties. For example Germanium, which is a material commonly used for infra-red lens elements, has a very high temperature coefficient of refractive index (dN/dT of about 2.7×10^{-4} per degree centigrade). This temperature sensitivity can give rise to problems when an infra-red lens or other optical system is to be used under different ambient temperature conditions. In particular, a lens may produce a satisfactorily focussed image at one temperature which is out of focus at another temperature. Generally the image can be restored to focus by appropriate movement of one or more elements of the lens but manual adjustment is often inconvenient and sometimes impractical. There is therefore a requirement for automatic adjustment or compensation for temperature changes, sometimes referred to as athermalisation which may be active or passive.

Although the problem is particularly severe in the case of infra-red optical systems, it can also occur in other optical systems such as some visible light lens systems in which focus can be lost through temperature change. There are also numerous non-optical situations requiring actuation or control responsively to temperature changes.

According to the present invention there is provided a temperature responsive actuator comprising a plurality of elements of "Shape Memory Effect" material each of which is arranged to expand and contract responsively to change in temperature over a different respective temperature range, the elements being effectively arranged in series so that in combination they provide an actuator output over an operating temperature range incorporating said different respective temperature ranges. The actuator preferably includes biassing means effective to apply a biassing load against the elements, and preferably the biassing means is arranged to apply a decreasing rate biassing load, which may be of varying decreasing rate, such as to produce a substantially linear actuator output with respect to temperature, i.e. such that displacement effected by the actuator bears a substantially straight line relationship to temperature.

The elements of "Shape Memory Effect" material are preferably in the form of coils which may be mounted on respective relatively slidable concentric sleeves such that expansion of a coil on one sleeve causes sliding movement of another sleeve. The actuator may include adjustment means for adjusting the permitted range of action of the respective, preferably coiled, elements. Thus the actuator may be adjusted to provide respective ranges of action which permit a smooth uninterrupted substantially linear actuator output over the full operating temperature range. The actuator may also include means to adjust the pre-load applied by the biassing means. Preferably a separate biassing means is provided for each of the plurality of elements adapted to the bias load requirements for the respective individual element.

Further according to the invention there is provided a temperature responsive actuator comprising an element, and preferably a coil, of "Shape Memory Effect" material, and biassing means effective to apply a biassing load against the element, the biassing means being arranged to apply a decreasing rate biassing load, which may be of varying decreasing rate, such as to produce a substantially linear actuator output with respect to temperature.

The biassing means may comprise a cam member, for example of basically cone-like shape, and means, such as rollers, held against the member, for example by tenson or compression springs, to apply a load thereto, the applied load decreasing as such means moves relatively to a cam surface of the cam member, for example a basically conical cam surface. The cam surface may be profiled to provide a varying decreasing rate of biassing load as it moves relatively to the load applying means.

Alternatively, the biassing means may comprise a spring device, such as a leaf spring, arranged to apply a decreasing rate biassing load, which may be of varying decreasing rate, as a member, such as a roller, engaging the spring device moves relatively thereto.

The decreasing rate biassing load means may be provided in conjunction with a constant rate biassing element, such as a compression spring, so as effectively to superimpose a decreasing rate, and possibly a varying decreasing rate, biassing load on the constant rate biassing load applied by such element.

The invention further provides an optical system (such as a lens), which may be an infra-red optical system (such as an infra-red lens), which is temperature sensitive, and a temperature responsive actuator comprising at least one element of "Shape Memory Effect" material arranged to effect displacement of an optical element (such as a lens element) in the optical system responsively to change of temperature. An actuator as set forth above is particularly, but not exclusively, suitable for use with an optical system which is temperature sensitive, and especially an infra-red optical system. The invention therefore further provides an optical system, such as a lens, incorporating a temperature responsive actuator as set forth above arranged to effect displacement of an optical element, such as a lens element, responsively to temperature changes. More particularly the invention further provides an infra-red optical system, such as an infra-red lens, incorporating a temperature responsive actuator as set forth above arranged to effect displacement of an infra-red optical element, such as an infra-red lens element, responsively to temperature changes. It will be appreciated, however, that an actuator in

temperature causes the member 18 to move along the sleeve 15 to the left as viewed in Figure 3 under the action of the biassing mechanism 22.

Between the end 19 of the outer sleeve 15 and an end rim 23 of the middle sleeve 16 is a second SME coil 24, while between the end 21 of the outer sleeve 15 and the other end 25 of the middle sleeve 16 is a biassing mechanism 26. Expansion of the coil 24 causes sliding movement of the outer sleeve 15 to the right as viewed in Figure 3 against the biassing action of the mechanism 26, and contraction of the coil 24 causes movement of the outer sleeve 15 to the left under the biassing action of mechanism 26.

Between the end 23 of the middle sleeve 16 and an end rim 27 of the inner sleeve 17 is a third SME coil 28, while between the end 25 of the middle sleeve 16 and the other end 30 of the inner sleeve 17 is a biassing mechanism 30. Expanson of the coil 28 causes sliding movement of the middle sleeve 16 to the right as viewed in Figure 3 against the biassing action of the mechanism 30, and contraction of the coil 28 causes movement of the middle sleeve 16 to the left under the biassing action of mechanism 30.

The calibration device 9, 10 of Figure 1 can be used to move the inner sleeve 17 axially along the shaft 2 thereby to position the actuator as a whole at a required location.

The SME coils 20, 24 and 28 each individually operate over a different respective temperature range so that in series combination they cover a relatively broad temperature range through which the actuator operates.

The biassing mechanisms 22, 26 and 30 are essentially of the same design. In Figure 3 each is shown for convenience simply as comprising a compression spring 31 as the biassing element although in practice, as described later, a bias mechanism which generates a decreasing rate load is in fact employed in conjunction with or instead of a simple compression spring.

As shown in Figure 3, one end of the compression spring 31 bears against the member to be biassed (i.e. the member 18 for mechanism 22, the end 21 of the outer sleeve 15 for mechanism 26, and the end 25 of the middle sleeve 16 for mechanism 30). The other end of the compression spring 31 bears against a stop 32 which is screw threaded onto an adjustment member 33. The position of the adjustment member 33 relative to the sleeve (15, 16 or 17) on which it is carried can be altered by means of screws 34 threaded through an end flange (21, 25 or 29) of the respective sleeve. The space between the adjustment member 33 and a projection 35 on the member to be biassed (such spaces being respectively indicated as "x", "y" and "z" in Figure 3) dictates the permissible extent of movement of the biassed member. The extent of each such space can be adjusted by altering the position of the respective adjustment member 33 as described above. The pre-load of the compression springs 31 can be individually adjusted by moving the stop 32 relative to the adjustment member 33.

By appropriate use of these adjustments the actuator can be arranged so that the respective SME coils 20, 24, and 28 effectively cover respective shares of the full temperature range over which the actuator is responsive. Thus the space "x" may be such as to cover a high part of the temperature range during which movement of the member 18 is caused by expansion or contraction of the first SME coil 20 (the other coils 24 and 28 being in their fully expanded state at that high part of the temperature range). The space "y" can then be such as to cover a medium part of the temperature range during which movement of the member 18 is caused by movement of the outer sleeve 15 through expansion or contraction of the second SME coil 24 (the coil 20 being fully contracted and the coil 28 fully expanded at that medium part of the temperature range). The space "z" is such as to cover a low part of the temperature range during which movement of the member 18 is caused by movement of the middle sleeve 16 (and hence also of the outer sleeve 15) through expansion or contraction of the third SME coil 28 (the other coils 24 and 20 being fully contracted at that low part of the temperature range). It will be understood that the apparatus is adjusted to provide smooth uninterrupted cover of the whole temperature range and that the total displacement capability of the actuator is "x + y + z".

In order to provide a highly linear actuator output, i.e. a substantially straight line relationship between displacement and temperature over the operative range, the biassing mechanisms 22, 26 and 30 are, as mentioned previously, in practice arranged to generate a decreasing rate biassing load.

One mechanism for achieving this is schematically shown in Figures 4 and 5. It comprises a basically cone-like member 36 disposed round the respective sleeve 37 (i.e. 15, 16 or 17 of Figure 3) and in abutment with the member 38 to be biassed (i.e. member 18, or sleeve 15, or sleeve 16 of Figure 3). The "conical" surface of the member 36 is profiled (e.g. by turning) to provide a form which suits the decreasing load rate requirements, and which can provide a varying rate of decrease. Disposed in equi-spaced relationship round this surface are a number of rollers 39 which are spring loaded against the surface by compression or tension or leaf or other springs and held at a fixed position along the length of the sleeve 37. Such springs are not shown in Figure 4 but Figure 5 shows a possible arrangement by way of example with three rollers 39 having their shafts connected by three respective tension springs 40. Figure 4 also shows an adjustable stop 41 (corresponding to stop 32 in Figure 3) which limits the permitted movement of the member 36 along the sleeve 37 (corresponding to the respective distance "x" "y" or "z" in Figure 3).

Figure 6 schematically shows an alternative possible decreasing rate bias load mechanism. This comprises a constant load rate compression spring 42 (similar to spring 31 in Figure 3) disposed between the member 38 to be biassed and an end flange or adjustable stop 43. A roller 44 is carried by the biassed member 38 and engages against a leaf spring 45 depending from an arm 46 connected to the stop or flange 43. As the biassed member 38 moves to the right as viewed in Figure 6 the roller 44

experiences a decreasing rate load from the leaf spring 45 (or an increasing rate load as it moves to the left). The leaf spring 45 can be angled and shaped (e.g. of varying width along its length) to vary the load it applies as required, and in particular to apply a varying rate of decrease of the biassing load.

A roller 44 and leaf spring are provided at a plurality of equi-spaced positions round the actuator axis (e.g. at two diametrically opposed positions or at three positions like the rollers 39 in Figure 5) in order to provide an equilibrium arrangement which minimises adverse frictional effects. The minimisation, and ideally avoidance, of friction is of particular importance since friction can produce adverse thermal effects which interfere with proper operation of the temperature responsive actuator. This is the primary reason for equi-spacing of devices, such as the rollers 44 and leaf springs 45, or the rollers 39 of Figure 5, round the actuator axis to provide an equilibrium arrangement.

It will be understood that a decreasing rate bias load mechanism, for example as described with reference to Figures 4 and 5 or Figure 6, is used for each of the biassing mechanisms 22, 26 and 30 of Figure 3. The improved linearity of displacement achievable by a decreasing rate bias load mechanism can be appreciated from Figure 7 which illustrates the output from a typical SME coil by plotting load against deflection (or displacement) at various temperatures and on which is shown a "Constant Rate"' bias load line and a "Decreasing Rate" bias load line. It will be seen that the latter cuts the temperature curves in a manner providing substantially equal deflection increments, i.e. provides a substantially linear displacement/temperature relationship.

An actuator as described above may, for example, provide a total linear displacement of about 30mm over a temperature range of 90°C extending from −40°C to +50°C. When used with an infra-red lens requiring displacement of an athermalising lens element through about 1.8mm over such 90°C temperature range, a velocity ratio of actuator output to lens carriage displacement of approximately 15:1 may be involved. It will be appreciated that the SME coils have a two way memory effect so as to effect displacement in both directions, i.e. so that the lens element is moved in one direction as the temperature rises and back again in the reverse direction as the temperature falls. Preferably the SME coils are directly exposed to the same ambient environment as the lens elements which are affecting the focus (image quality) rather than enclosed in an actuator housing or the like which could cause different temperature conditions.

It will be understood that the lens carriage moved by the actuator may carry more than one lens element. It will further be understood that the actuator, although particularly suited for use with an infra-red lens, could be used for other optical systems in which temperature responsive movement of a lens or other optical element is required, or indeed for non-optical applications such as multi-temperature control of industrial ovens, environmental test chambers, etc., and other applications requiring temperature control or compensation or recordal (e.g. pen recorders).

It will further be understood that the three SME coil arrangement specifically shown and described is given by way of illustration and example and that any reasonable desired number of coils arranged effectively in series could be employed. The actuator can therefore be adapted to cover any desired temperature range for which SME coils are available. In some circumstances adequate linearity of actuator output may be achievable by application of an equal and averaged bias load to each of the coils but it is preferable that the respective bias loads should be adapted to the individual coils. Also in some circumstances a single coil arrangement may be useful.

It will be appreciated that the biassing mechanism of Figures 4 and 5 could incorporate a constant load rate biassing element such as a compression spring (corresponding to the spring 42 of Figure 6) so that the decreasng rate biassing load means 36, 39, 40 superimposes a decreasing rate, and possible a varying decreasng rate, biassing load on the constant rate biassing load applied by such element (in similar fashion to the way that the decreasing rate biassing load means 44,45 of Figure 6 superimposes a decreasing rate, and possibly a varying decreasing rate, biassing load on the constant rate biassing load applied by the spring 42). Conversely, the constant load rate compression spring 42 could be omitted from the biassing mechanism of Figure 6 so that the biassing load is applied by the leaf spring 45 and roller 44 arrangement alone, this arrangement being adapted to provide the required biassing load (of decreasing rate and possibly varying decreasing rate).

CLAIMS

1. A temperature responsive actuator comprising a plurality of elements of "Shape Memory Effect" material each of which is arranged to expand and contract responsively to change in temperature over a different respective temperature range, the elements being effectively arranged in series so that in combination they provide an actuator output over an operating temperature range incorporating said different respective temperature ranges.

2. An actuator according to Claim 1 including biassing means effective to apply a biassing load against the elements.

3. An actuator according to Claim 2 in which the biassing means is arranged to apply a decreasing rate biassing load.

4. An actuator according to Claim 3 in which the biassing means is arranged to apply a biassing load of varying decreasing rate.

5. An actuator according to any preceding claim in which the elements of "Shape Memory Effect" material are in the form of coils.

6. An actuator according to Claim 5 in which the coils are mounted on respective relatively slidable concentric sleeves such that expansion of a coil on one sleeve causes sliding movement of another

sleeve.

7. An actuator according to any preceding claim including adjustment means for adjusting the permitted range of action in the respective element.

8. An actuator according to any of Claims 2 to 4, or any of Claims 5 to 7 when dependent from any of Claims 2 to 4, including means to adjust the pre-load applied by the biassing means.

9. An actuator according to any of Claims 2 to 4, or any of Claims 5 to 7 when dependent from any of Claims 2 to 4, or Claim 8 including a separate biassing means for each of the plurality of elements.

10. An actuator according to Claim 3 or Claim 4, or any of Claims 5 to 9 when dependent from Claim 3 or Claim 4, in which the biassing means comprise a cam member and means held against the member to apply a load thereto, the applied load decreasing as such means moves relative to a cam surface of the cam member.

11. An actuator according to Claim 10 in which the cam member is of basically cone-like shape.

12. An actuator according to Claim 10 or Claim 11 in which the means held against the member comprise rollers.

13. An actuator according to any of Claims 10 to 12 in which the means held against the member are held by tension or compression springs.

14. An actuator according to any of Claims 10 to 13 in which the cam surface is profiled to provide a varying decreasing rate of biassing load as it moves relatively to the load applying means.

15. An actuator according to Claim 3 or Claim 4, or any of Claims 5 to 9 when dependent from Claim 3 or Claim 4, in which the biassing means comprise a spring device arranged to apply a decreasing rate biassing load as a member engaging the spring device moves relatively thereto.

16. An actuator according to Claim 15 in which the spring device is a leaf spring.

17. An actuator according to Claim 15 or Claim 16 in which the member engaging the spring device is a roller.

18. An actuator according to Claim 3 or Claim 4, or any of Claims 5 to 9 when dependent from Claim 3 or Claim 4, or any of Claims 10 to 17, in which the decreasing rate biassing load means is provided in conjunction with a constant rate biassing element so as effectively to superimpose a decreasing rate biassing load on the constant rate biassing load applied by such element.

19. An actuator according to Claim 18 in which the constant rate biassing element is a compression spring.

20. An optical system having a temperature responsive actuator according to any preceding claim arranged to effect displacement of an optical element in the optical system responsively to change of temperature.

21. An infra-red optical system incorporating a temperature responsive actuator according to any of Claims 1 to 19 arranged to effect displacement of an infra-red optical element responsively to change of temperature.

22. An actuator according to any of Claims 1 to 19, or an optical system according to Claim 20 or 21 in which the actuator is, operatively connected with an angularly movable or rotatable member.

23. An actuator or optical system according Claim 22 in which angular movement of the angularly movable or rotatable member causes linear movement of another member by means of a cam and cam follower arrangement.

24. An actuator or optical system according to Claim 23 in which the cam and cam follower arrangement comprises a plurality of equi-spaced basically ramp-like cams mounted on one of the members for engagement by a corresponding plurality of equi-spaced cam follower rollers mounted on the other member.

25. An actuator or optical system according to Claim 24 in which the cam surfaces are profiled to effect the required movement.

26. A temperature responsive actuator substantially as described herein with reference to Figure 3, or Figures 3, 4 and 5, or Figures 3 and 6, of the accompanying drawings.

27. An optical system incorporating a temperature responsive actuator according to Claim 26 substantially as described herein with reference to Figures 1 and 2 of the accompanying drawings.

28. A temperature responsive actuator for the adjustment of an optical system to compensate for changes in the system due to temperature changes over an operating temperature range, wherein a plurality of "Shape Memory Effect" elements are provided each of which expands and contracts responsive to temperature changes over a different temperature zone within the operating temperature range so that in combination the elements provide a compensating actuator output over the operating temperature range and wherein the actuator output is used to effect the necessary compensating adjustments in the optical system.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1982.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.